Quantifying BMP effects on sediment delivery at forest road stream crossings

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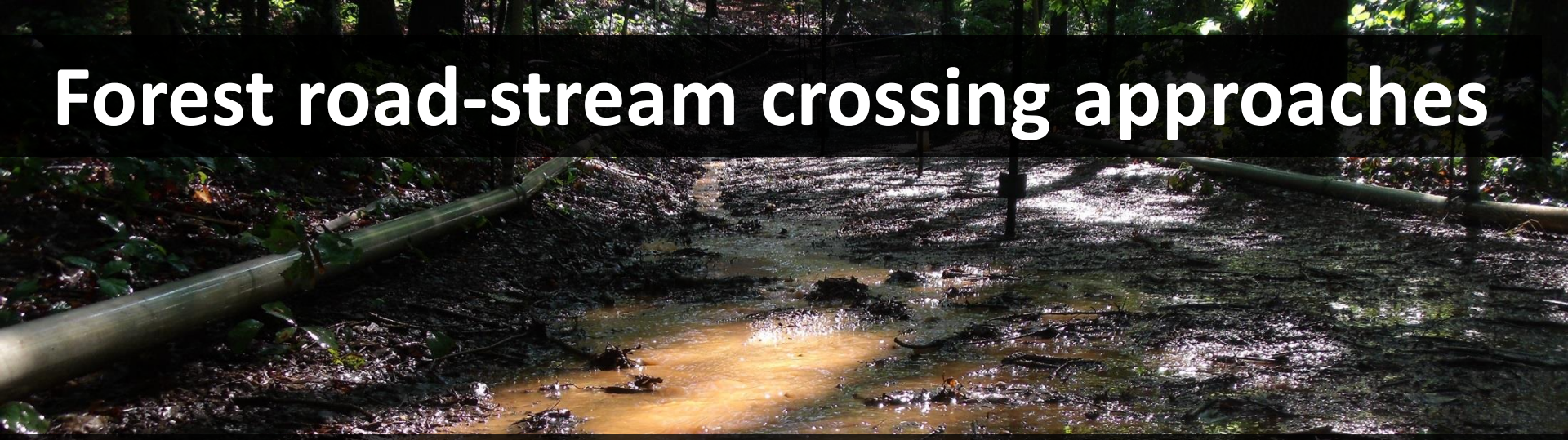
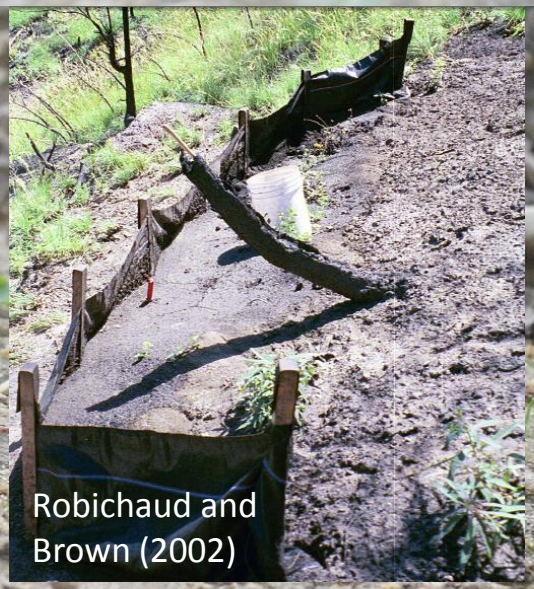
Forest road-stream crossing approaches



- Sediment delivery potential is greatest at the road-stream interface
- Issue has sparked legislative debates about CWA permits and NPSP status of forest roads

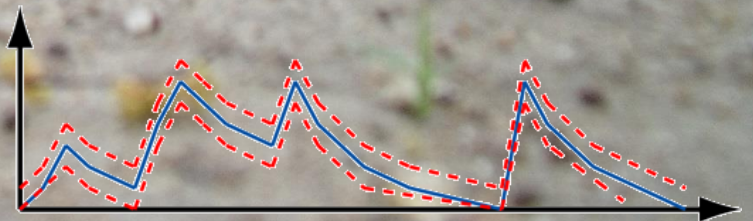
Need to demonstrate the application of cost-effective BMPs… **How?**

Turton et al. (2009)



Robichaud and Brown (2002)

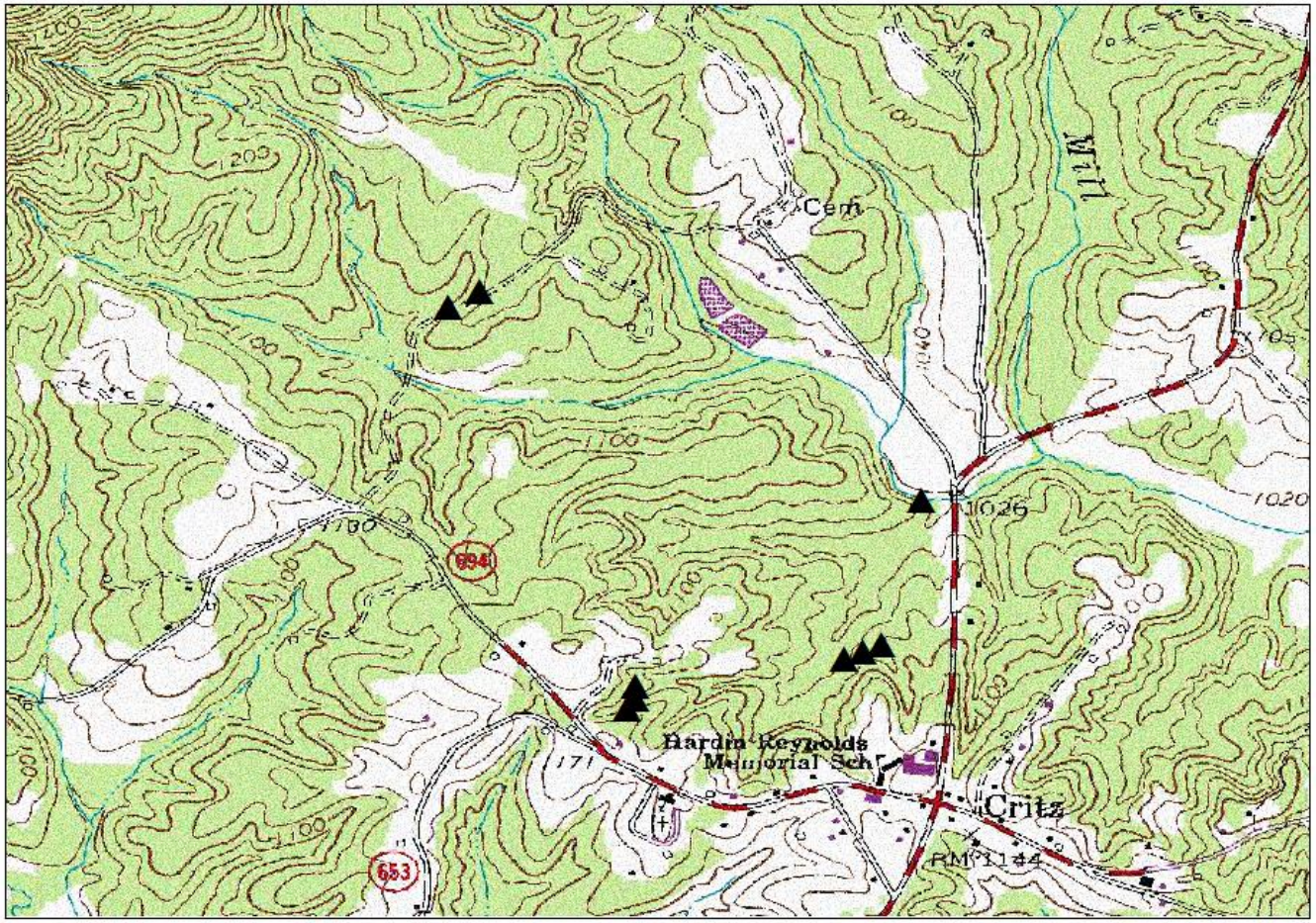
FSWEPP



Objectives

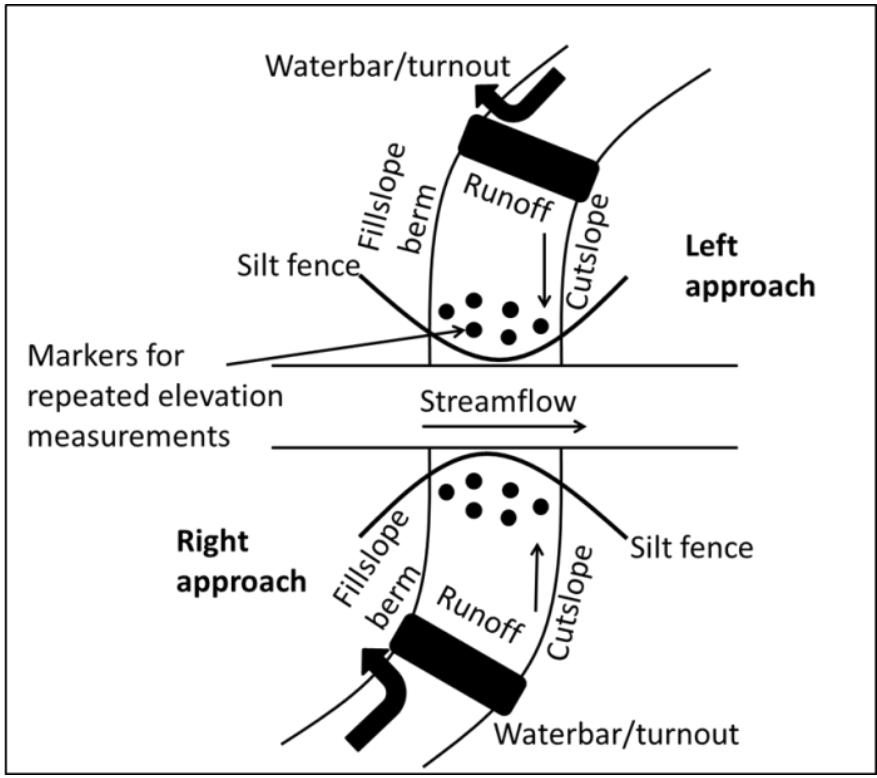
- Quantify annual sediment delivery rates for bare and graveled stream crossing approaches
- Quantify surface hydrologic processes and sediment transport of stream crossing approaches during storm events
- Utilize field data in soil erosion models (USLE-forest, WEPP) and evaluate model performance at the road-stream interface

Reynolds Homestead



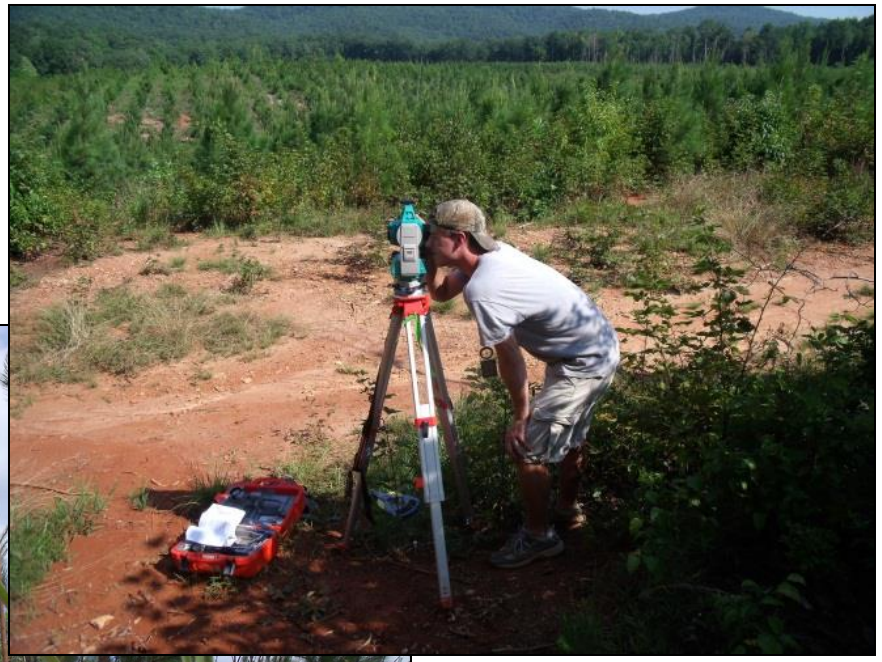
Road approach study sites

Site Bare 3 after a thunderstorm on 22-Jun-2012.



Plan view of two idealized stream crossing approaches.

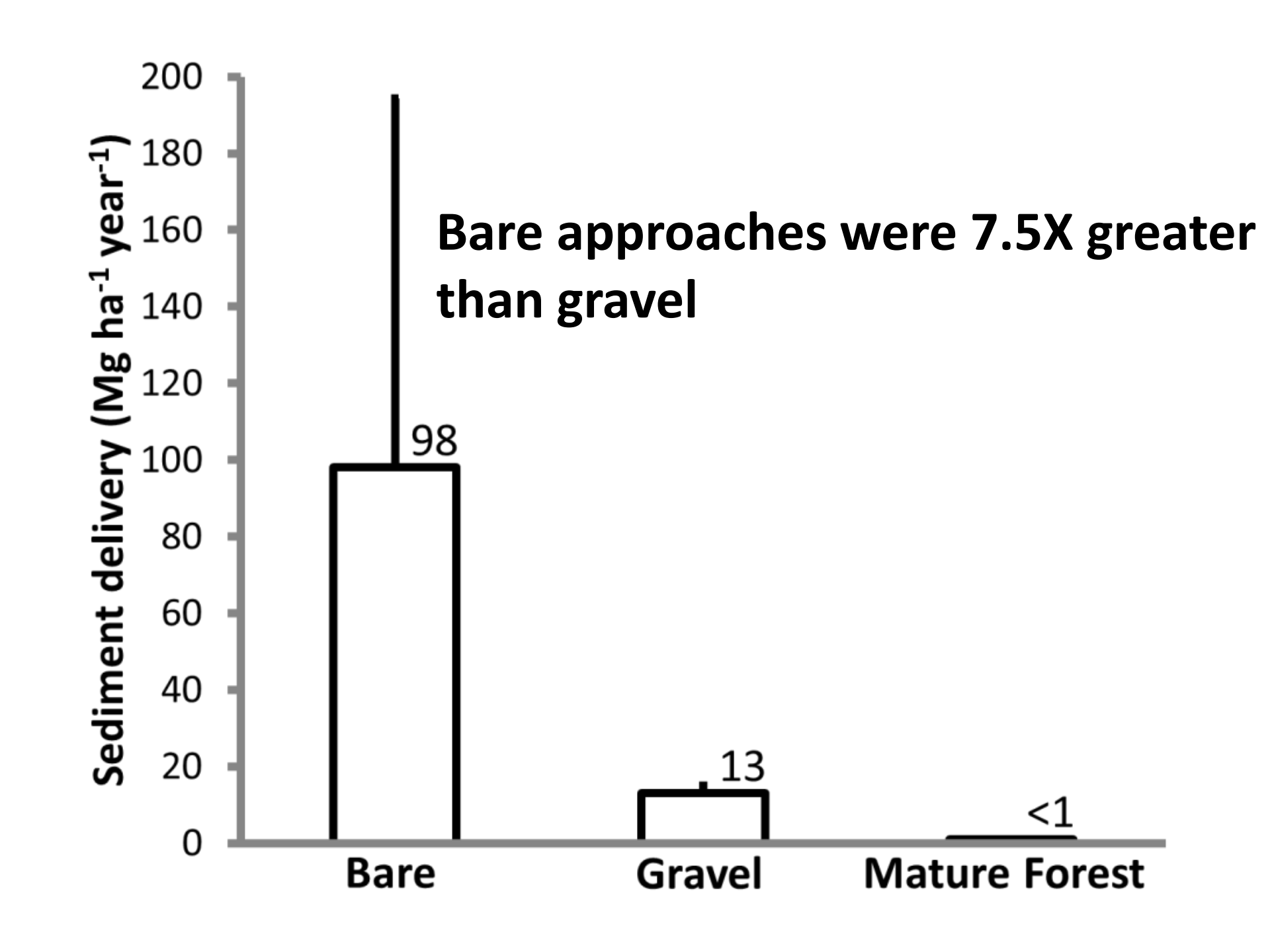
Repeated measurements of sediment delivery

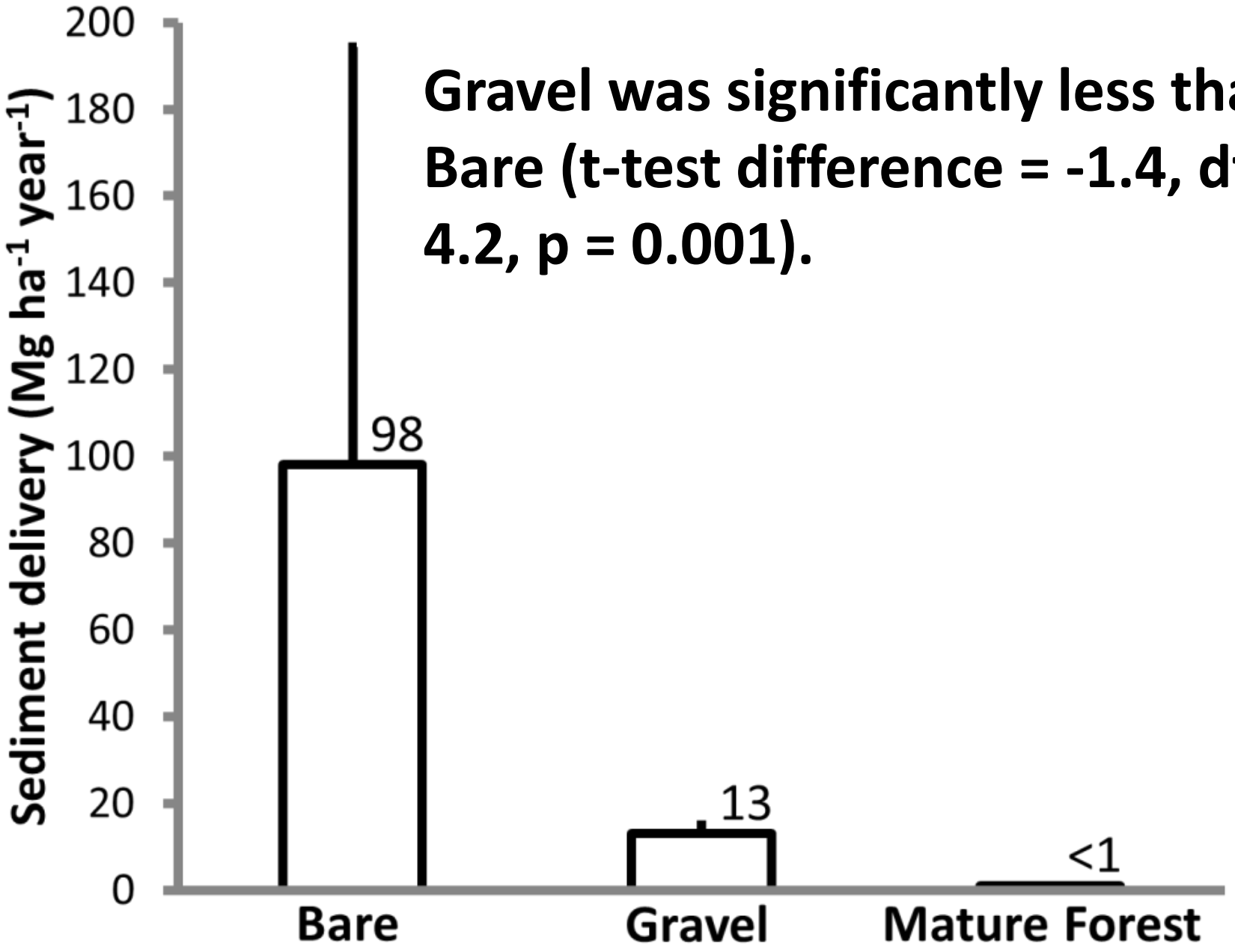


Statistical design

- Annual sediment delivery rates (Mg ha^{-1} yr^{-1})
  - Two-sample t-test by surface type (bare, gravel)
  - N = 9

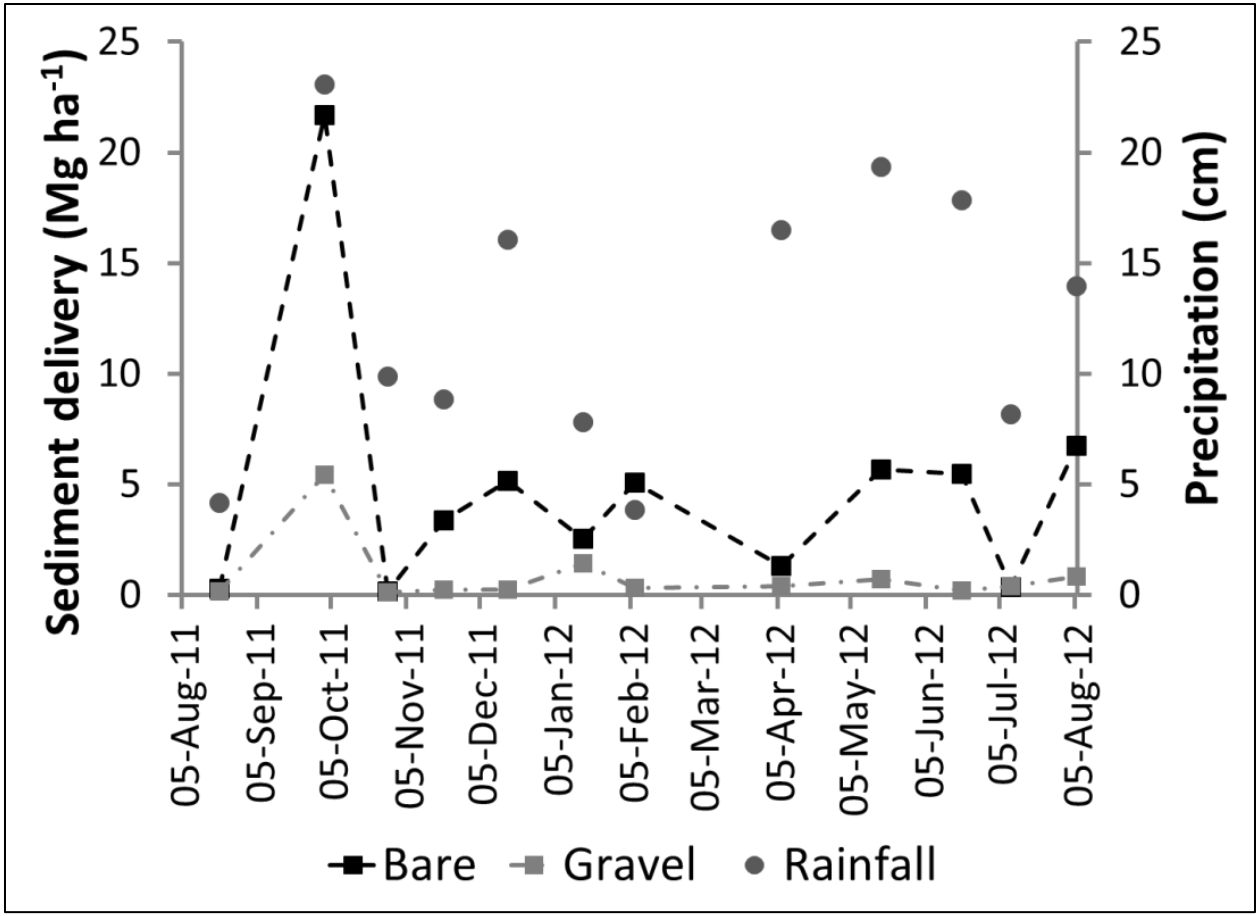
- Repeated measurements of sediment (Mg ha^{-1})
  - Repeated measures ANOVA
  - Model components: Surface Type (bare, gravel), Time (measurements 1-12), Surface*Time interaction
  - N = 108


Sediment delivery (Mg ha-1 year-1)
200
180
160
140
120
100
80
60
40
20
0
98
13
<1
Bare
Gravel
Mature Forest
Bare approaches were 7.5X greater than gravel



Gravel was significantly less than Bare (t-test difference = -1.4, df = 4.2, p = 0.001).

Sediment delivery rates over time



Effect	Numerator df	Denominator df	F value	Pr > F
Road surface	1	6	38.32	0.0008
Time	11	66	13.60	<0.0001
Surface*Time	11	66	0.95	0.4979

Field data to parameterize soil erosion models

- USLE-forest: A = RKLSCP
- C sub-factors were evaluated 3 times from Aug. 2011 to Aug. 2012.
- Erosion predictions were averaged by site to produce annual estimates of sediment delivery (Mg ha^{-1} yr^{-1}) (N=9).

Building WEPP hillslope profiles

- 4 main files needed to run WEPP (Windows ver. 2012.8)
  - Climate
  - Slope
  - Soil
  - Management

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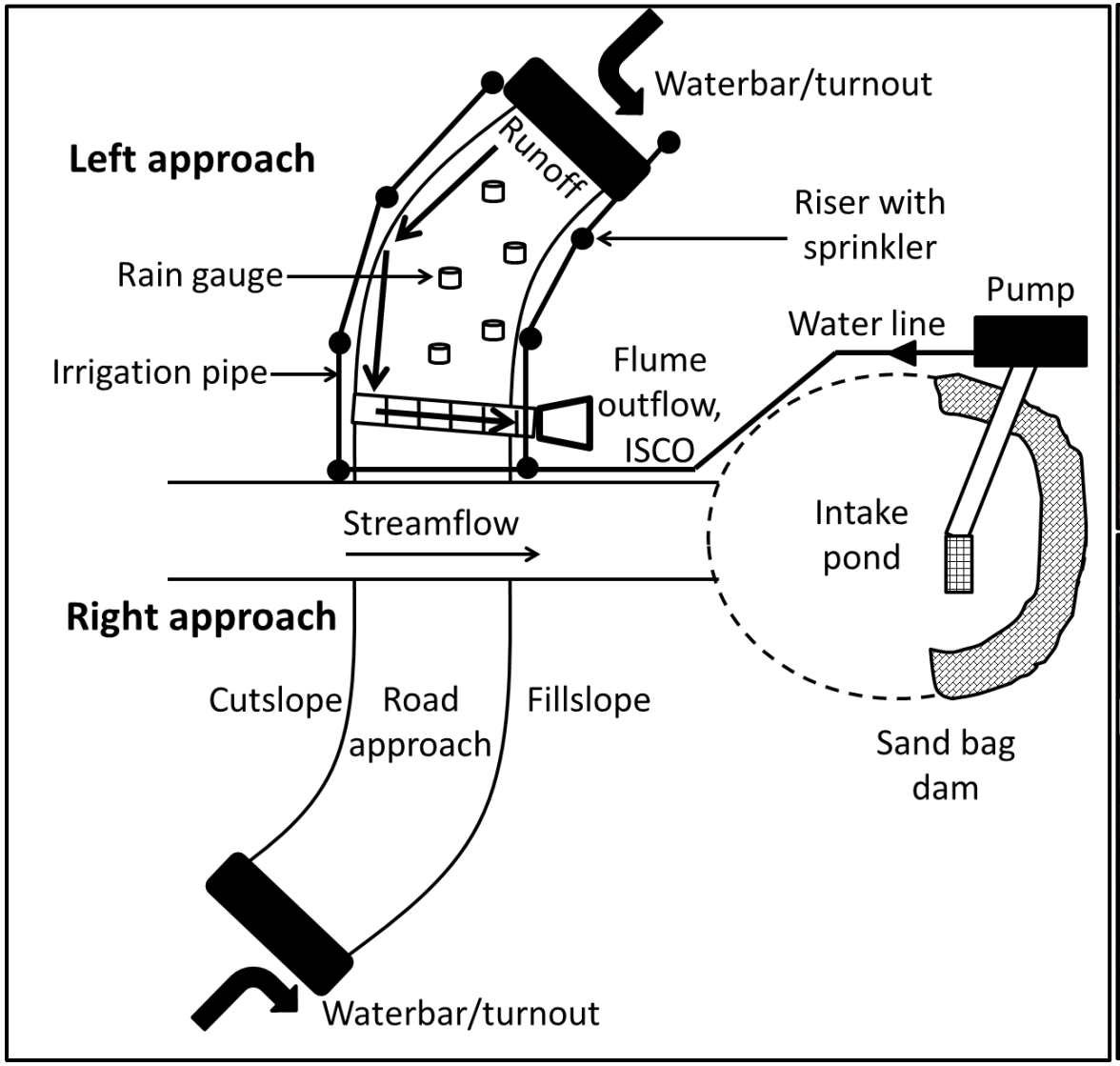
Site	Measured erosion ($Mg\ ha^{-1}\ year^{-1}$)	Modeled erosion			
		USLE-forest		WEPP	
		Erosion estimate ($Mg\ ha^{-1}\ year^{-1}$)	Percent deviation (modeled v. measured)	Erosion estimate ($Mg\ ha^{-1}\ year^{-1}$)	Percent deviation (modeled v. measured)
Bare 4	287	44.8	-84	245.4	-14
Bare 5	85	29.1	-66	124.4	46
Bare 3	41	51.2	25	6.1	-85
Bare 1	41	66.2	61	3.1	-92
Bare 2	34	43.1	27	1.6	-95
Gravel 2	16	0.3	-98	0.0	-100
Gravel 1	13	0.7	-95	0.0	-100
Gravel 4	12	2.5	-80	0.0	-100
Gravel 3	10	0.3	-97	0.0	-100

Neither model performed well in predicting annual sediment delivery rates

Both models predicted substantial annual sediment delivery rates for sites with inadequate surface cover and minimal sediment delivery rates for the gravel approaches

WEPP performed better than USLE-forest in ranking the problem road approaches

Rainfall simulation study



Bare treatment

10-19% cover

Low Gravel treatment

34-60% cover

High Gravel treatment

50-99% cover

Gravel cost

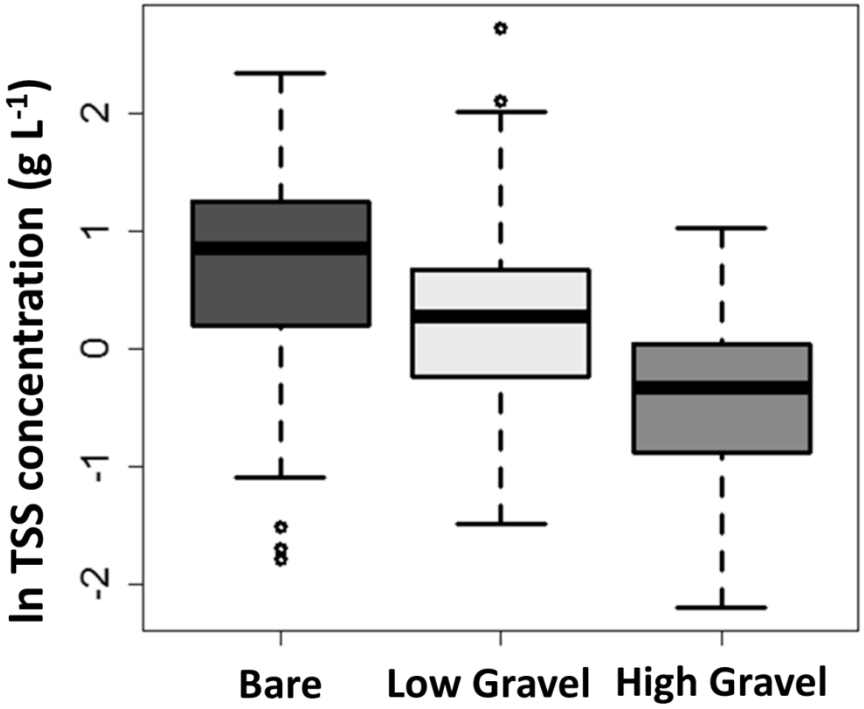
Gravel volume (m^3) = Depth (0.08 m) X Width (2.5-3.2 m) X Length (9.8 m)

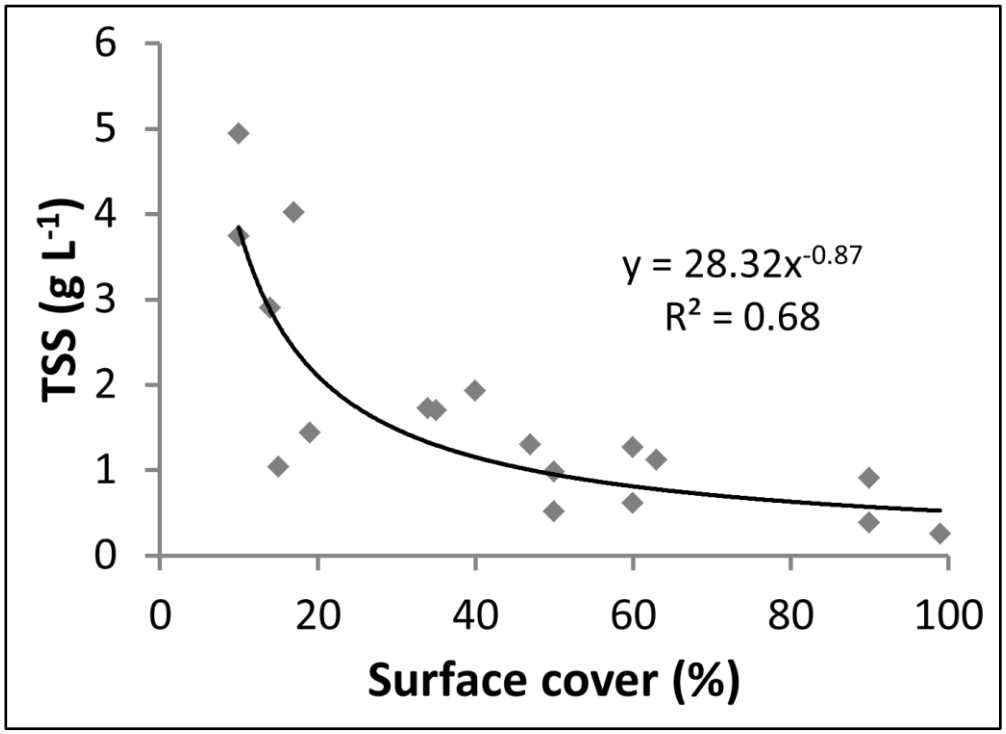
Gravel mass (tonnes) = Volume (m^3) X 2.65 tonnes m^{-3}

Gravel cost ($) = Mass (tonnes) X $27.56/tonne

Mean cost for Low Gravel = $151.99; High Gravel = $303.97

Sediment-reduction efficacy of gravel





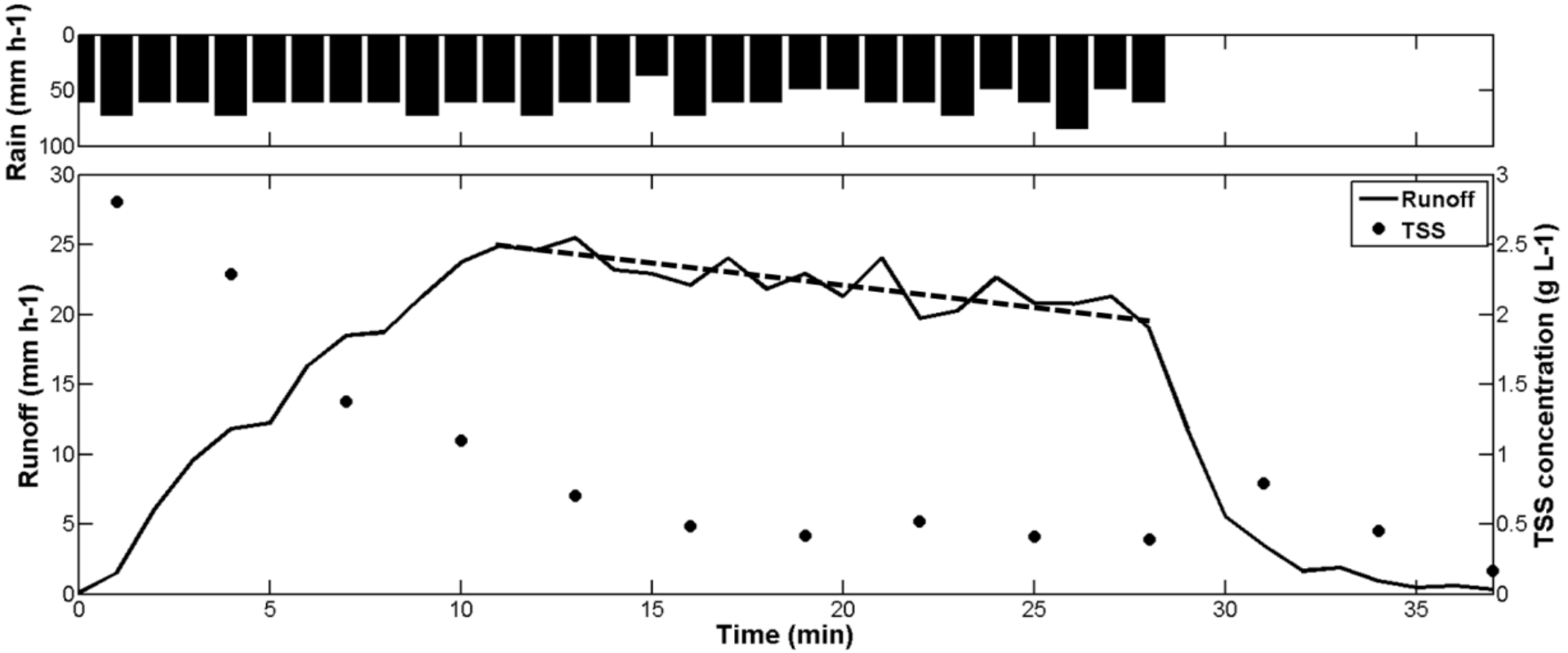
Median TSS concentration for the Bare treatment was 2.6 and 3.5X greater than Low Gravel and High Gravel, respectively

Cost-effectiveness of gravel

- $152 reduced TSS by a factor of 2.6
- $304 reduced TSS by a factor of 3.5

- Implies that cost effectiveness could be increased by minimizing the drainage length of stream crossing approaches

Use of hydrographs and sediment transport data to model event-based sediment delivery with WEPP



Monte Carlo approach

- Following Brazier et al. (2000)
- Uncertainty in WEPP model input and outputs

1. Specify a range for WEPP's most important model parameters
2. Run WEPP 5000 times for each experiment (N = 54)
3. Evaluate model performance based on observed runoff and sediment

Can WEPP predict the treatment effects observed in field experiments?

Conclusions

- Problem road approaches had poor water control and minimal surface cover
- Judicious BMP usage can reduce road approach sediment delivery
- Despite poor accuracy, USLE-forest and WEPP identified problem stream crossing approaches


Questions?